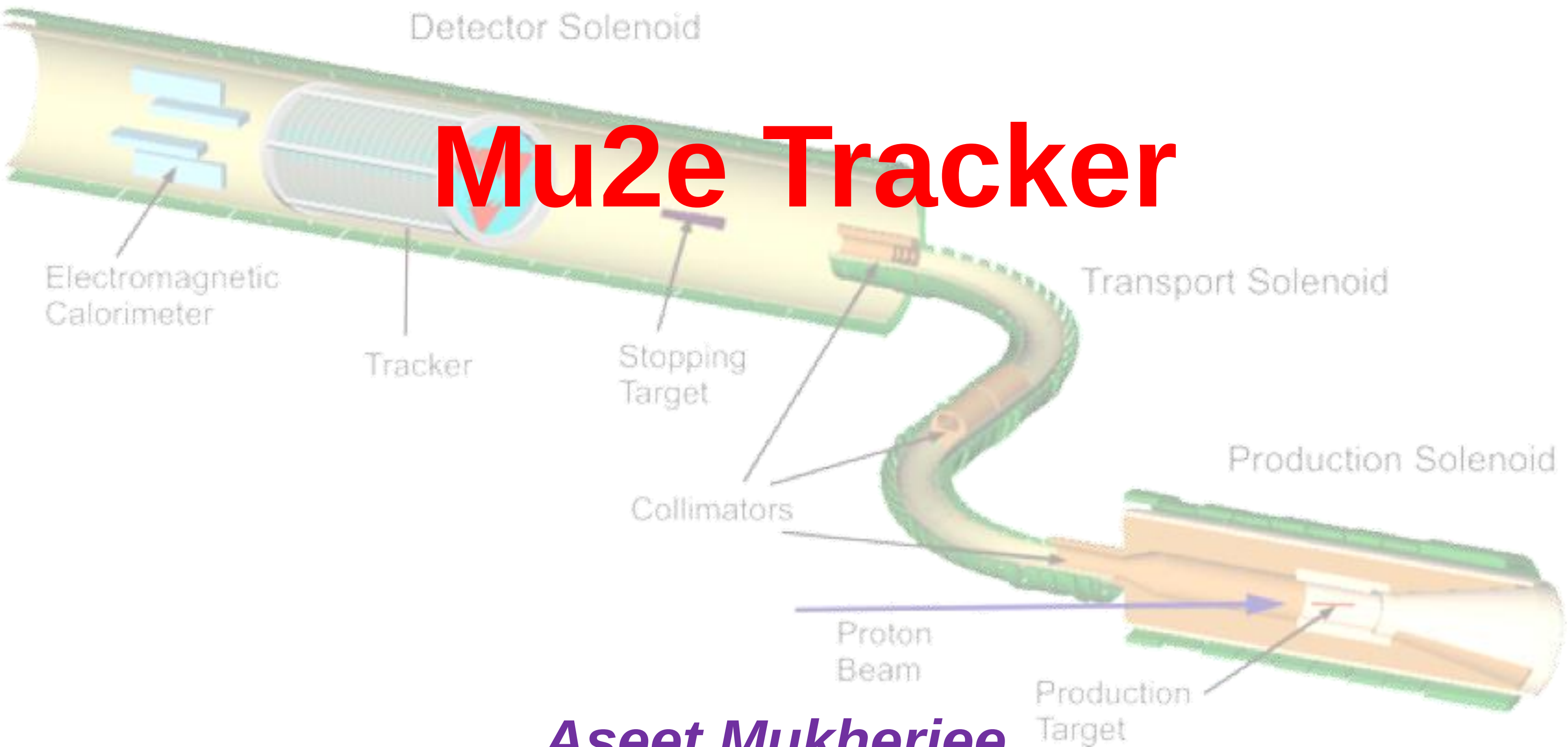
Mu2e Tracker



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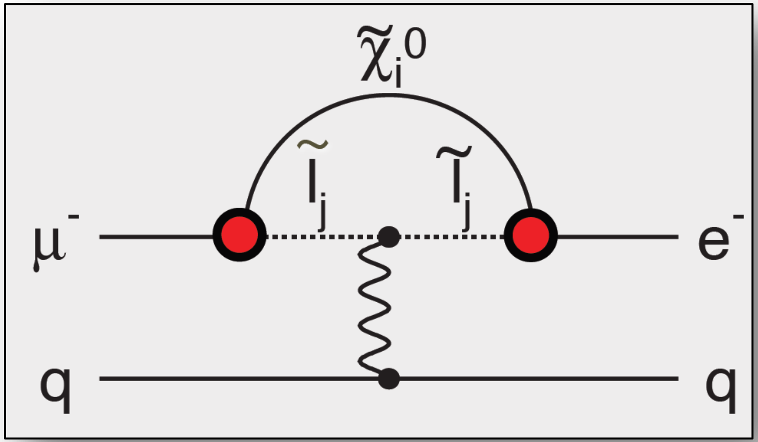
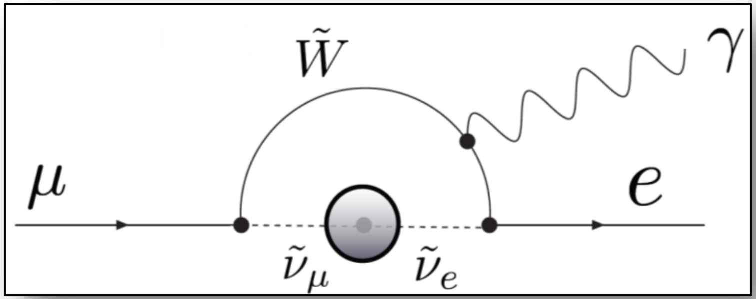
16 Jun 12

What are we looking for?

- Flavor Changing Neutral currents
  - Explore SUZY mass scales ~104 TeV $\rightarrow$ ~50 events
  - Signature: Electrons approaching the kinematic limit of 105MeV



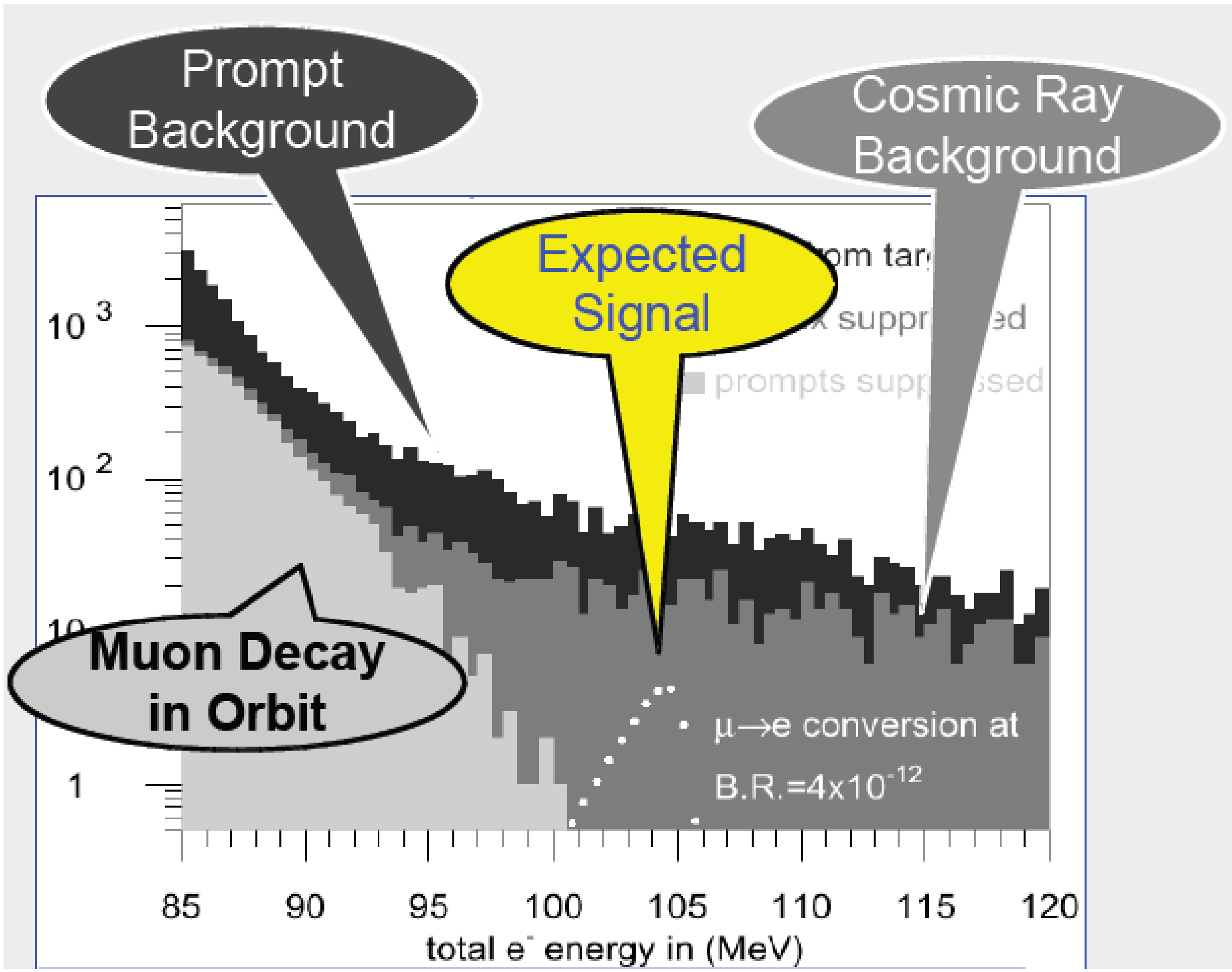
- SM $\mu^- \rightarrow e^- \gamma$ expected rate very low BR < 10^{-54}



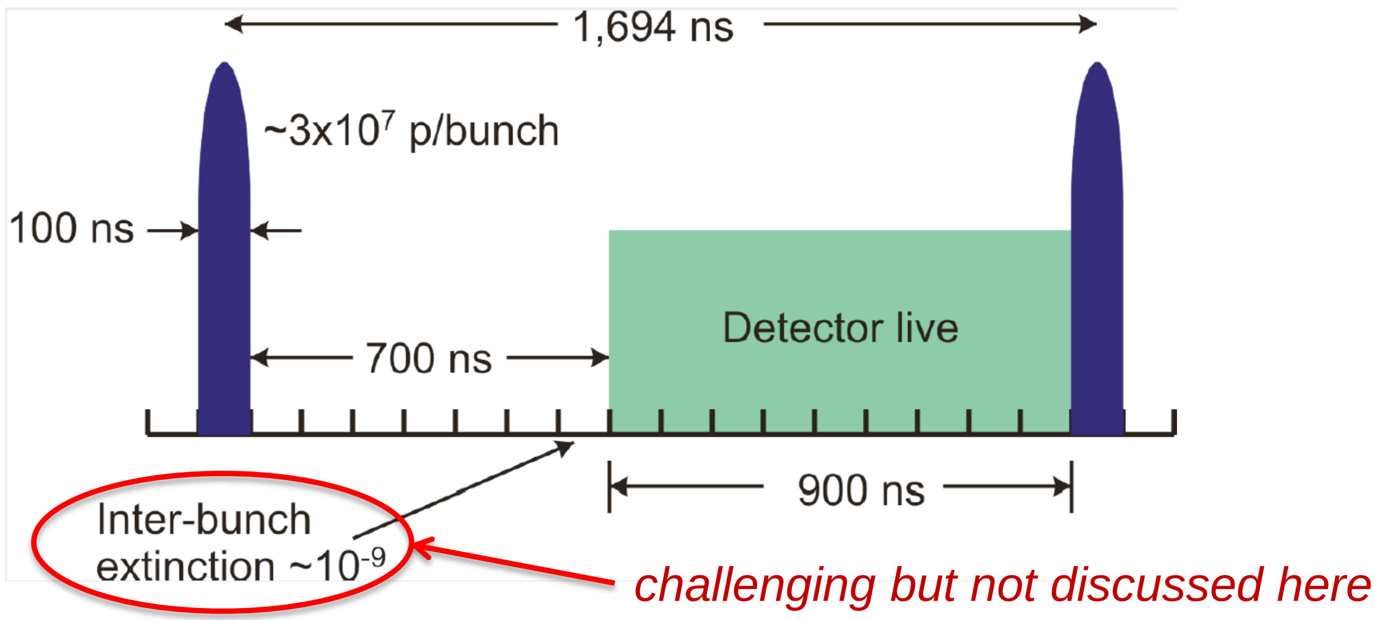
Basic Method

- Low energy muon beam strikes target
- μ ranges out in target, orbits nucleus
- Lifetime ~700nsec in aluminum
  - ~40% muon capture $\mu^- N \rightarrow \nu_\mu N'$
    N' disintegration releases protons and neutrons
  - ~60% decay in orbit $\mu^- \rightarrow \mathrm{e}^- \nu_\mu \bar{\nu}_e$
    These "DIO" electron energy typically < ½ the kinematic limit
- Hope a few do something more interesting

Previous Experiment: SINDRUM II



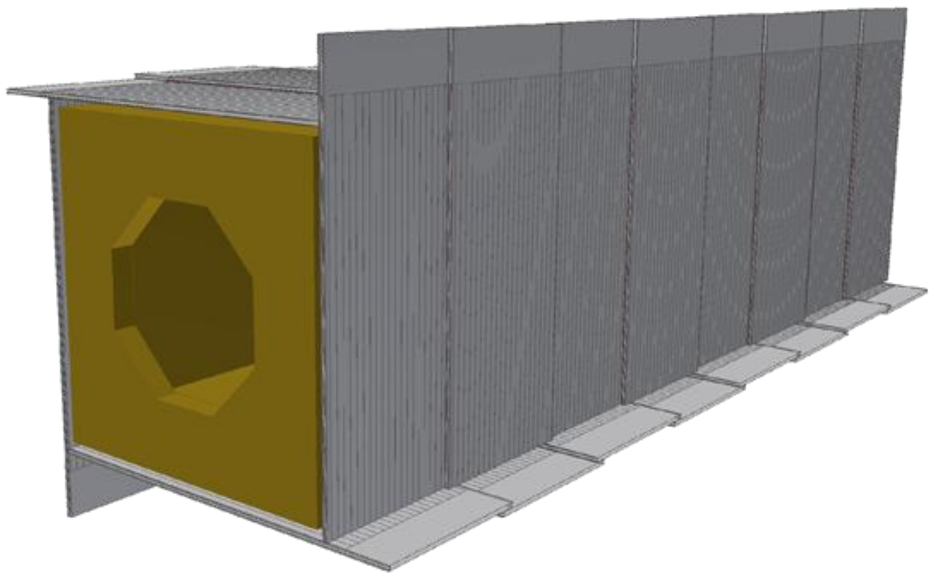
Reducing Prompt Background

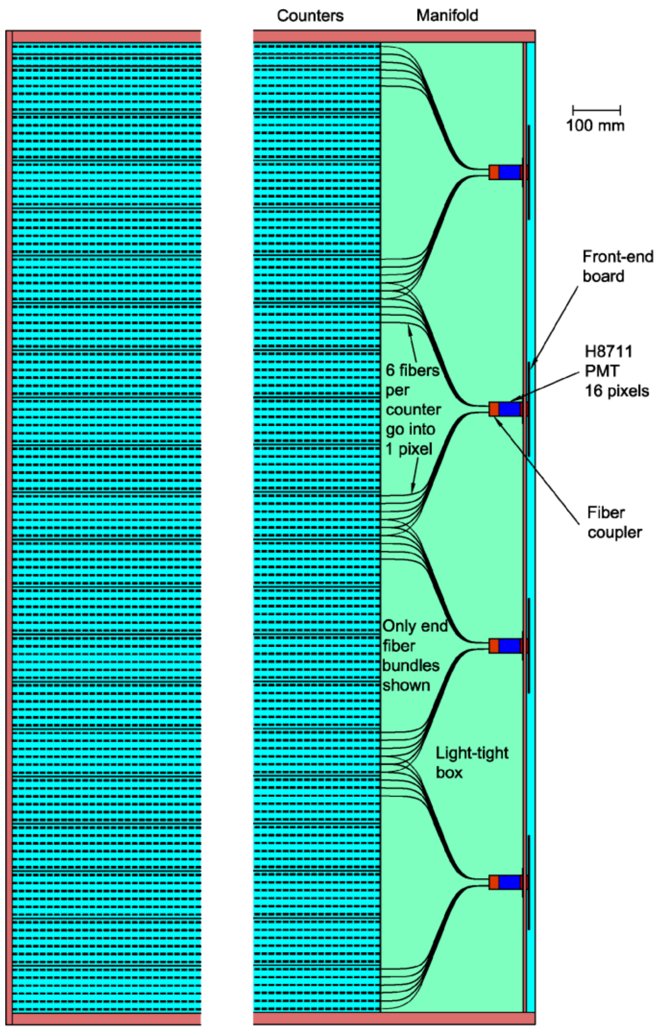


- Pulsed beam
- Ignore first 500-700nsec
- What isn't eliminated is more easily measured

Reducing Cosmic Background

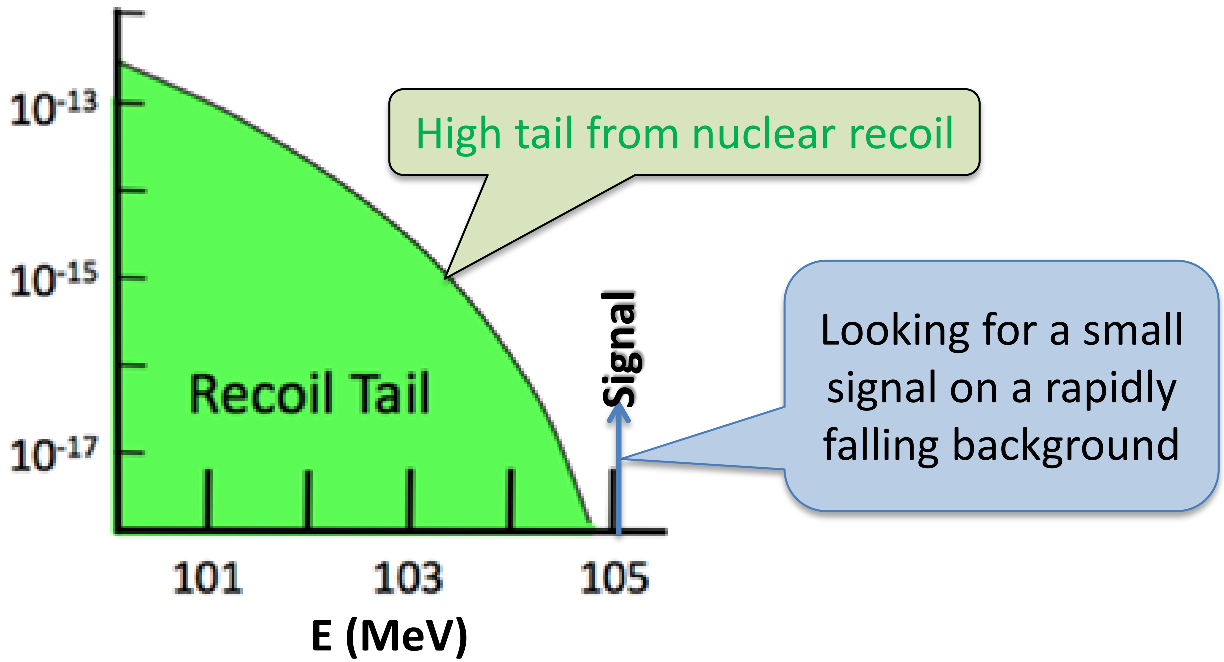
- Efficient, full coverage cosmic ray veto
- Higher intensity



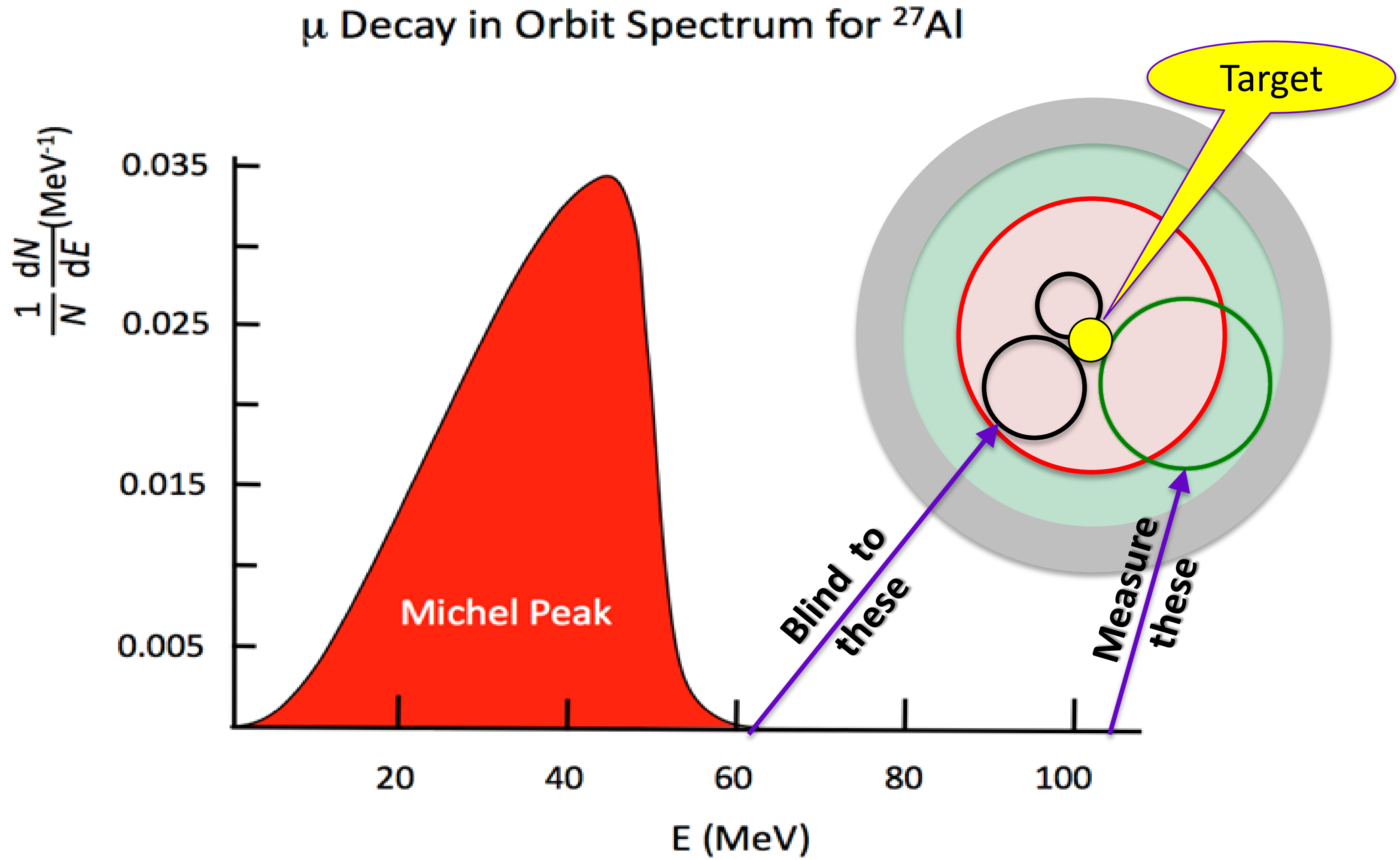


Irreducible Backgrounds

- Rely exclusively on momentum resolution to understand and reduce these
  - Radiative π decay $\pi^{-}N \rightarrow \gamma N'$ $\gamma \rightarrow e^{+}e^{-}$
  - DIO "leakage"

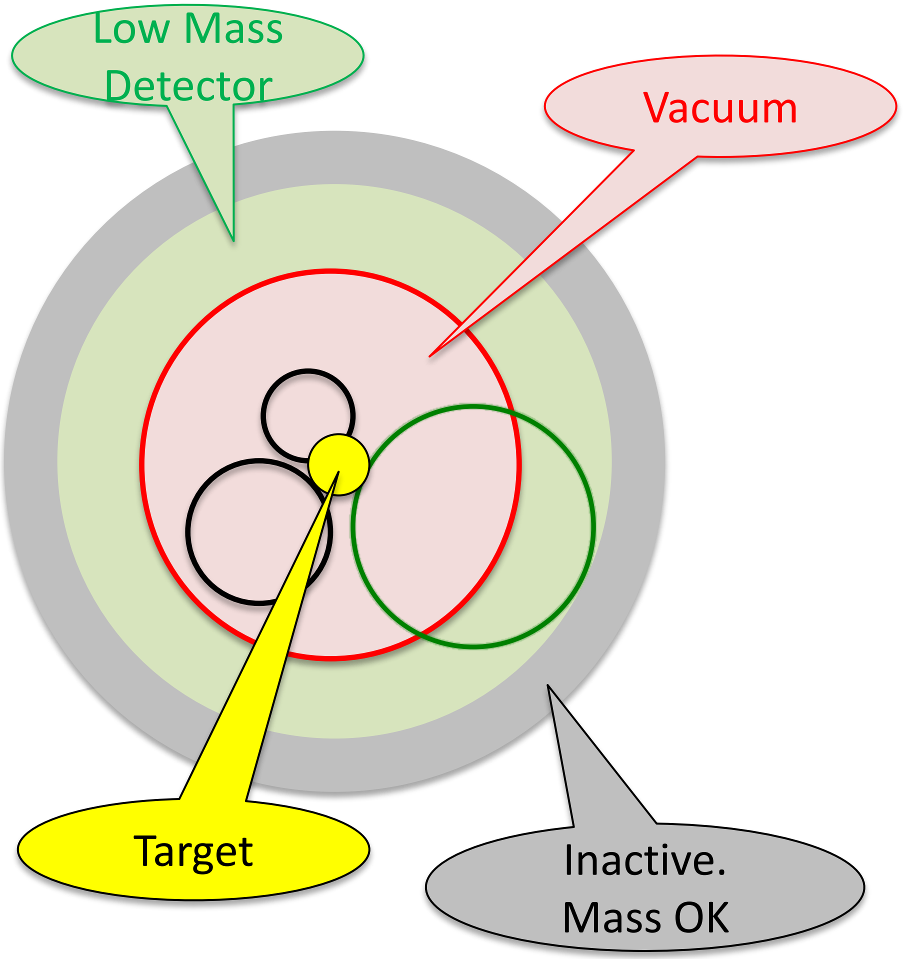


Detector Geometry



Detector Geometry

- Material in DIO region
  $\rightarrow$ scattering
  $\rightarrow$ high rate
- Vacuum needed ... but complicates detector
  - Gas detectors
    - Must not leak
    - Must handle Δp~1 atm
  - Any detector
    - Heat flow must be engineered in



What Detector(s) to Use?

- Many backgrounds scale with resolution
- Particles of interest are ~100MeV electrons

⇒ Low Mass Tracker

- Large volume to be instrumented
- Cost is *always* an issue!

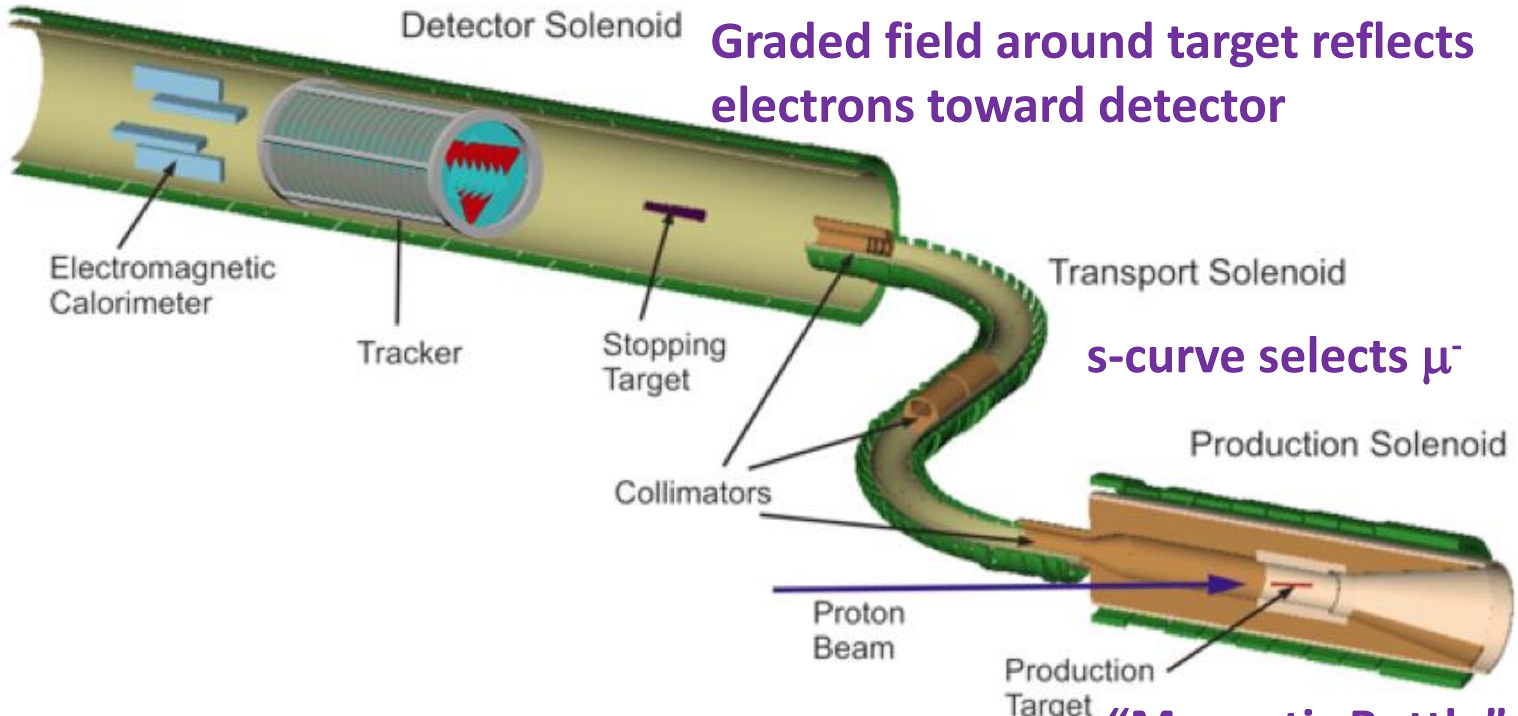
⇒ Drift Chamber

- Drift chambers benefit from time reference, aka t_0
- Looking for a very rare event
  Want internal confirmation

⇒ EM Calorimeter downstream of Tracker

Mu2e Layout

Uniform field around detector



Graded field around target reflects electrons toward detector

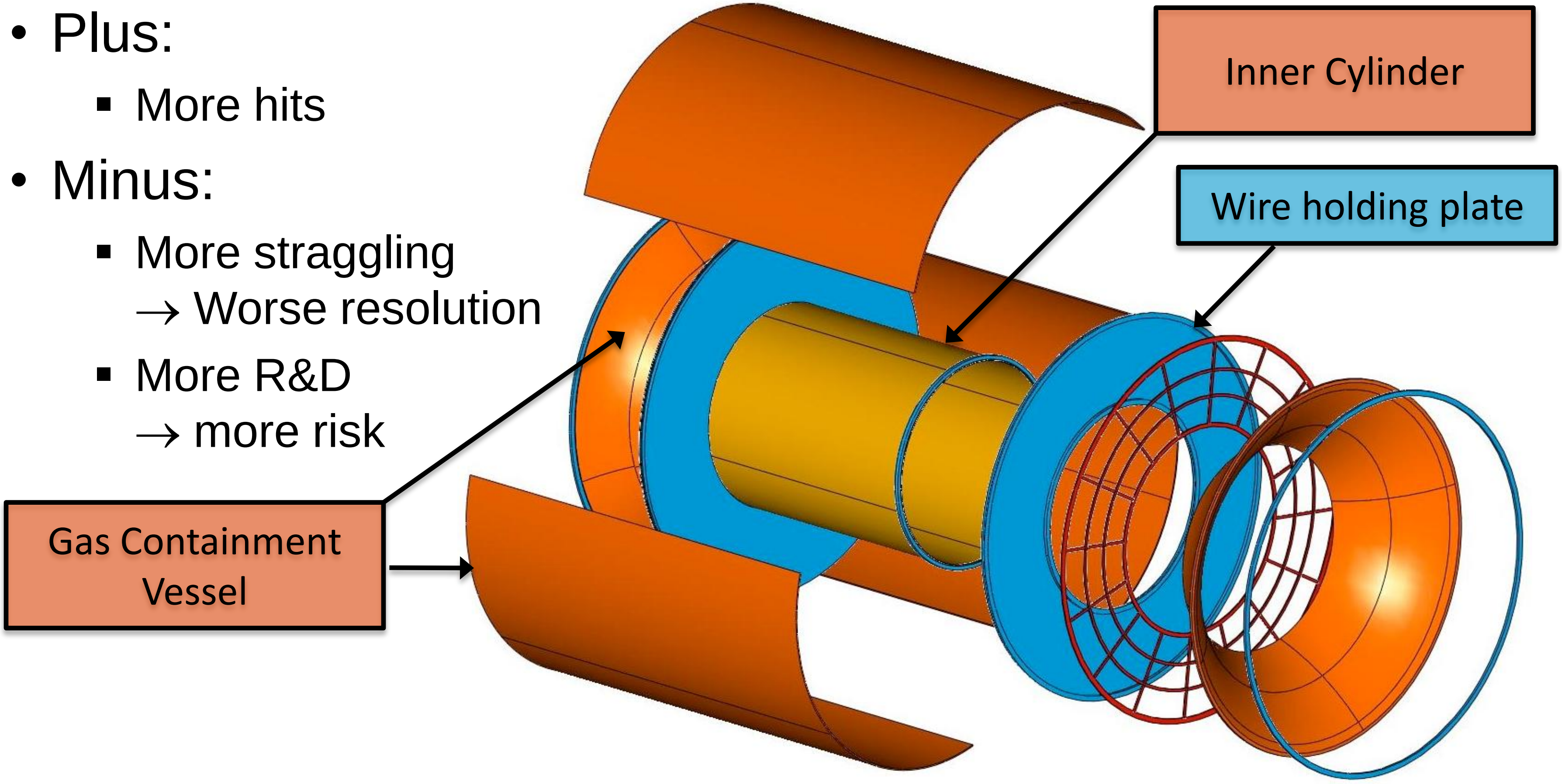
s-curve selects μ^-

"Magnetic Bottle" traps desired πs

Tracker Option: Open Cell

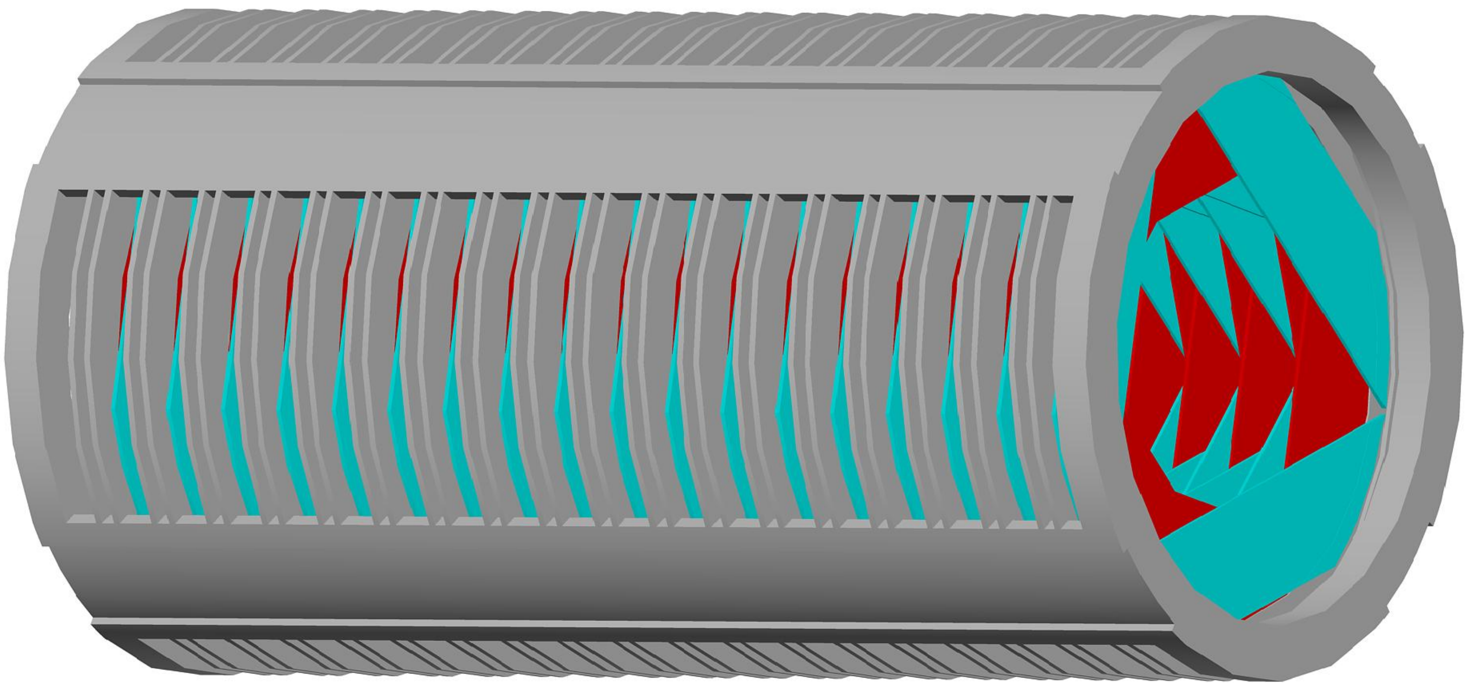
Open cell option with wires for anode & cathode

- Plus:
  - More hits
- Minus:
  - More straggling
    → Worse resolution
  - More R&D
    → more risk

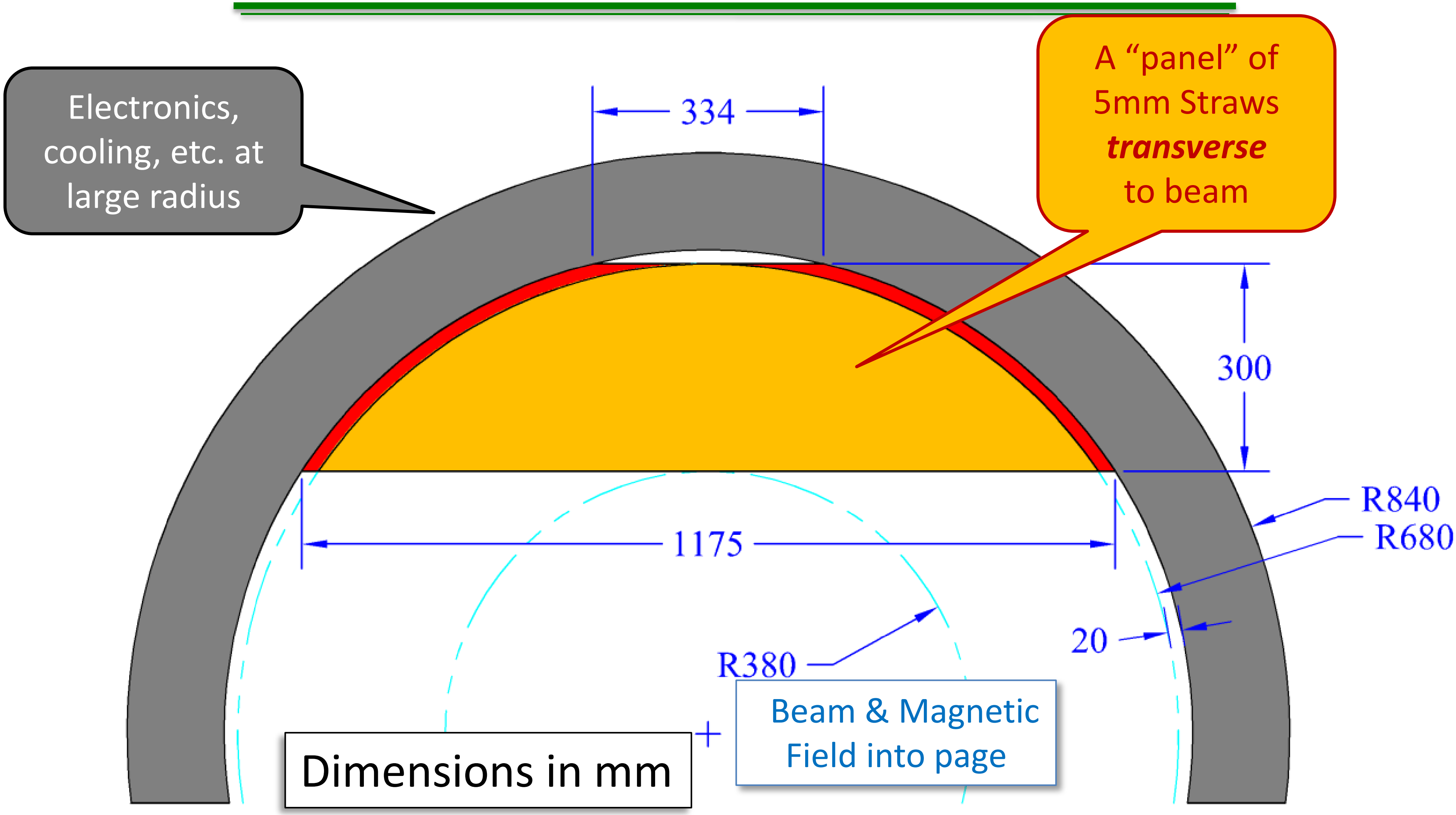


Tracker Option: Straws

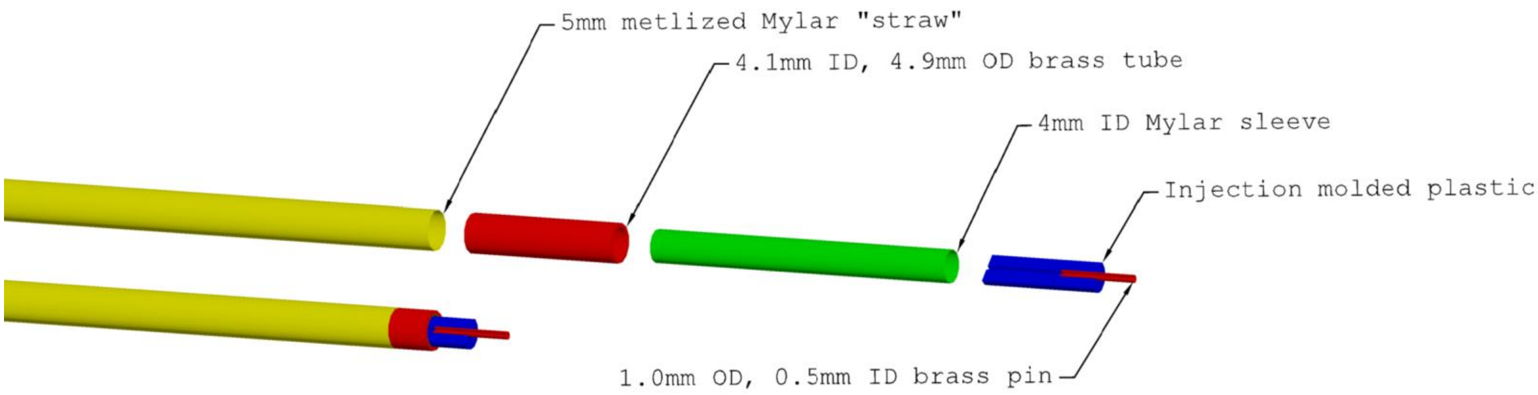
- 18 “stations” with straws transverse to beam
- Vacuum between stations to keep mass down
- Naturally moves readout and support to large radii

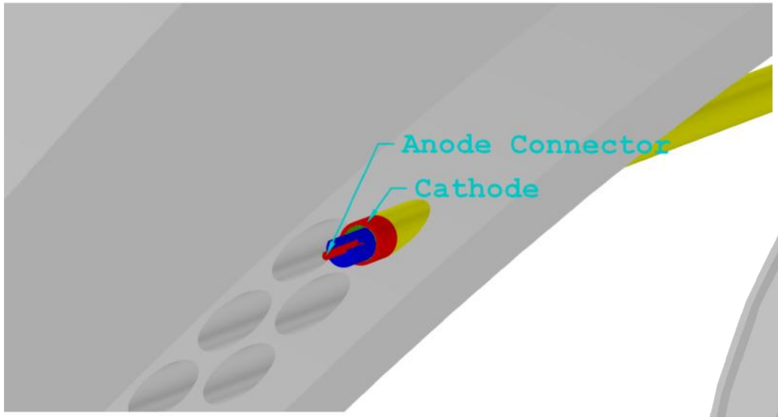


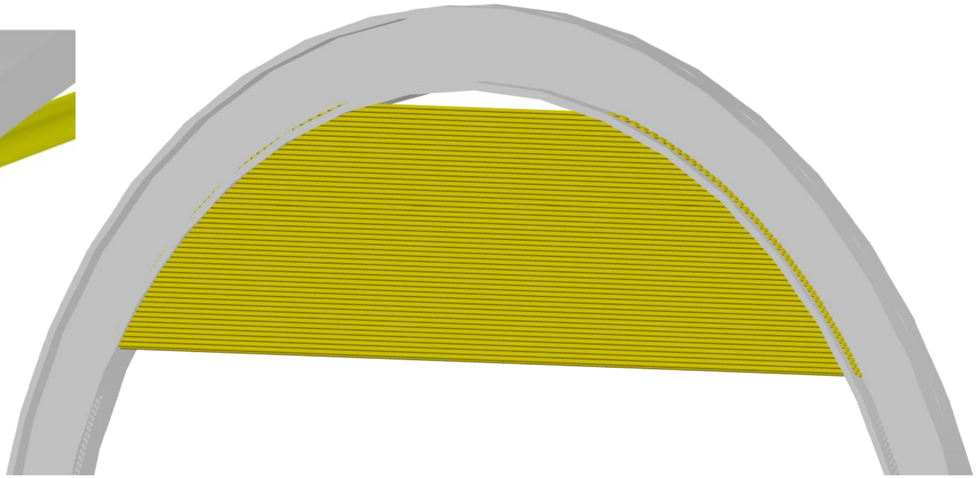
Basic Design



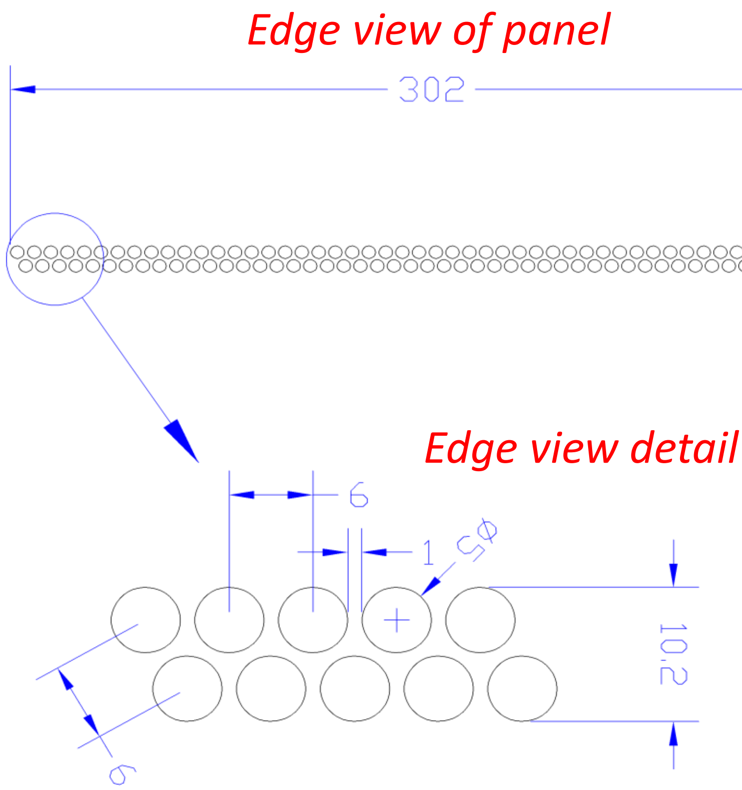
Straw Termination







Panel



- 5mm OD straws …
  like ATLAS TRT
  - Known to handle high rates
  - For lowr mass:
    Use 15µm Mylar
    instead of 25µm Kapton
- Gaps between straws …
  like NA62 (CERN)
  - Allows looser tolerance
  - Less concern about
    expansion due to pressure

Gaps and Double Layer

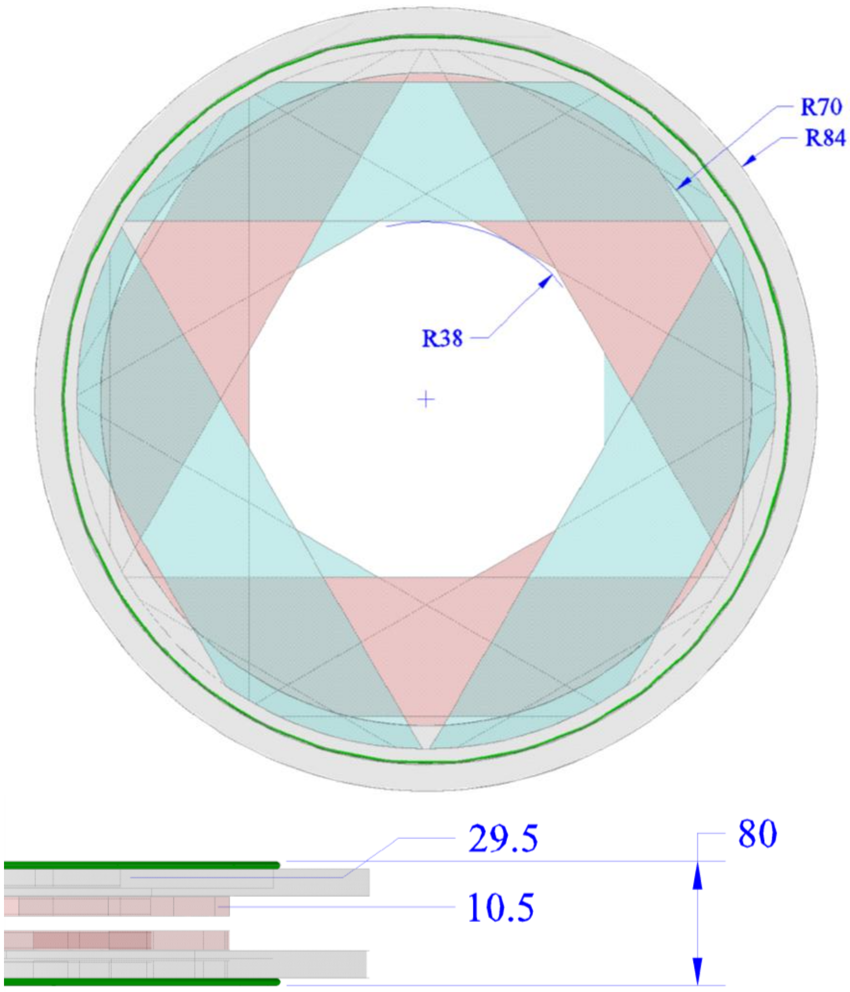
Close packed

- Pluses
  - Self-supporting (without tension)
  - Fewer straws
    $\rightarrow$ Lower mass, cost
- Minuses
  - Accumulate straw tolerances
  - Sensitive to expansion due to differential pressure ... acts differently when operated in vacuum

Gaps between Straws

- Pluses …
  - Precision of straw less critical
  - Expansion has no cumulative affect
    $\rightarrow$ operation ~same in vacuum and air
- Minuses
  - Need to tension straws
  - Need double layer to avoid holes in coverage

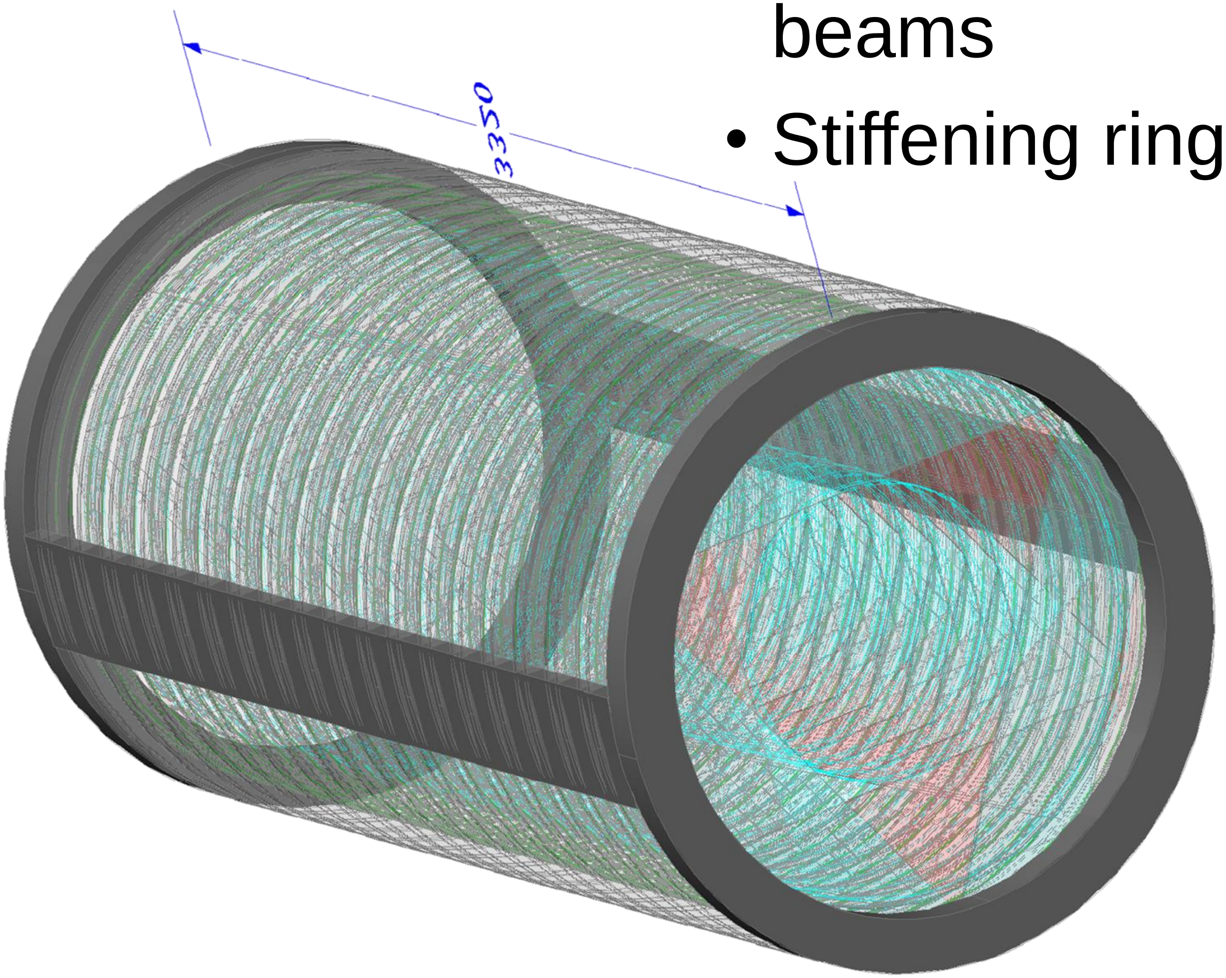
Station



- 12 "panels" at 30° rotations, form a station
- Made from two "planes" with 6 panels each
- 30° stereo angles give 400μm resolution along wire
- Straw termination and readout at r>70cm

Support

- Two or four support beams
- Stiffening rings at ends



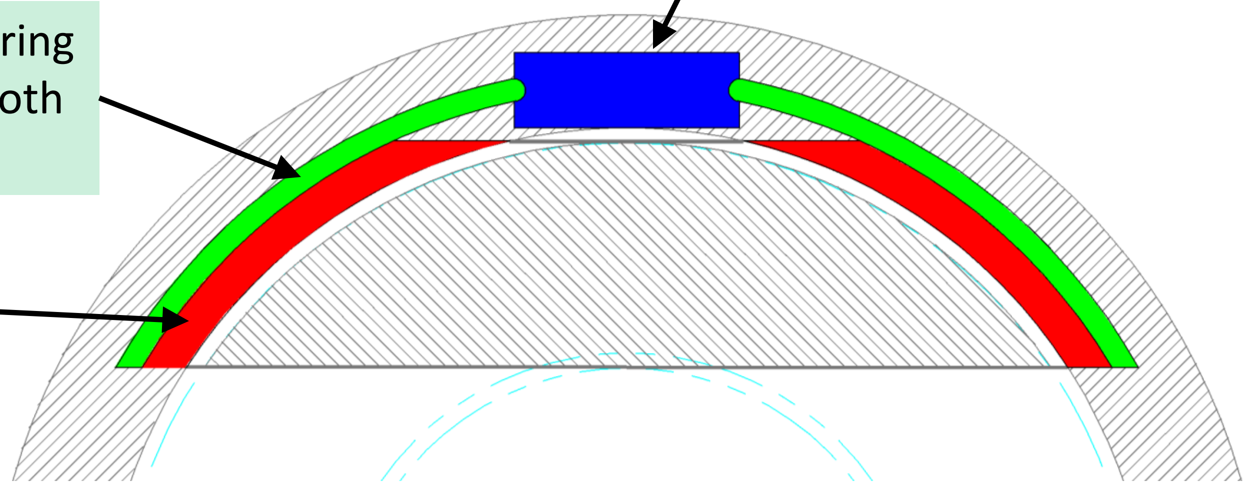
Front End Electronics

- Preamps at straw ends
- Signals carrued to common point (simplifies time division)
- TDC: 100ps for drift time
  20ps for time division

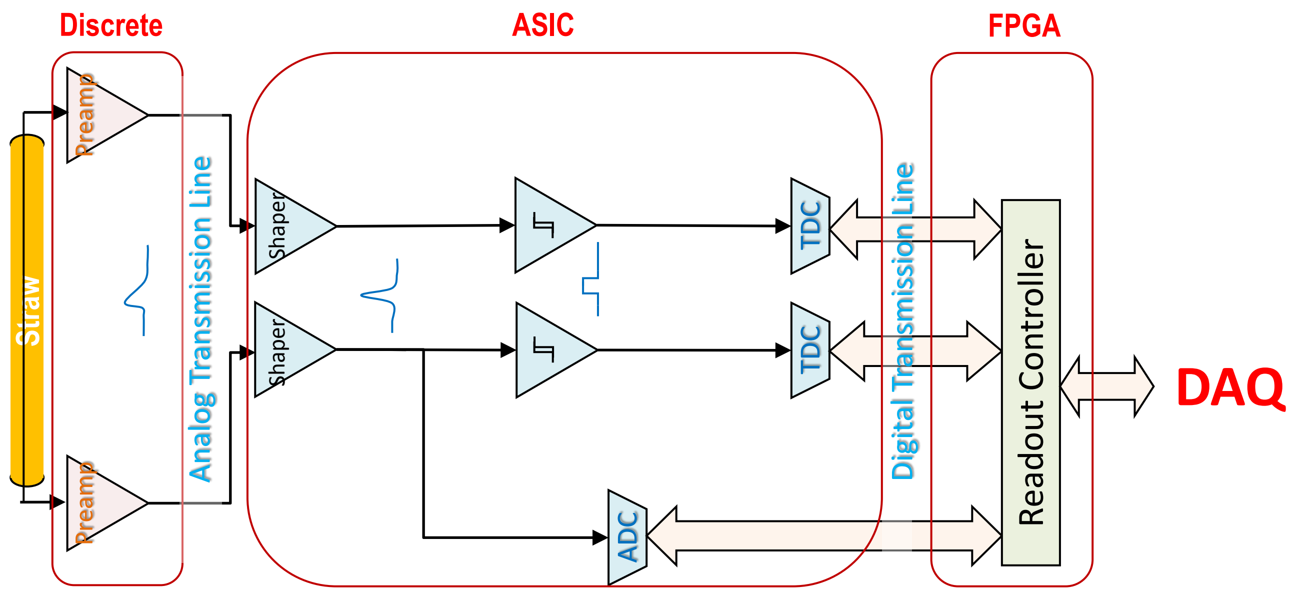
➢Signal shaping
➢Digitizers (ADC, TDC)
➢Communication
➢Controllers

Cable (or PC board) bring analog signals from both ends together

Discrete parts preamps and HV circuitry



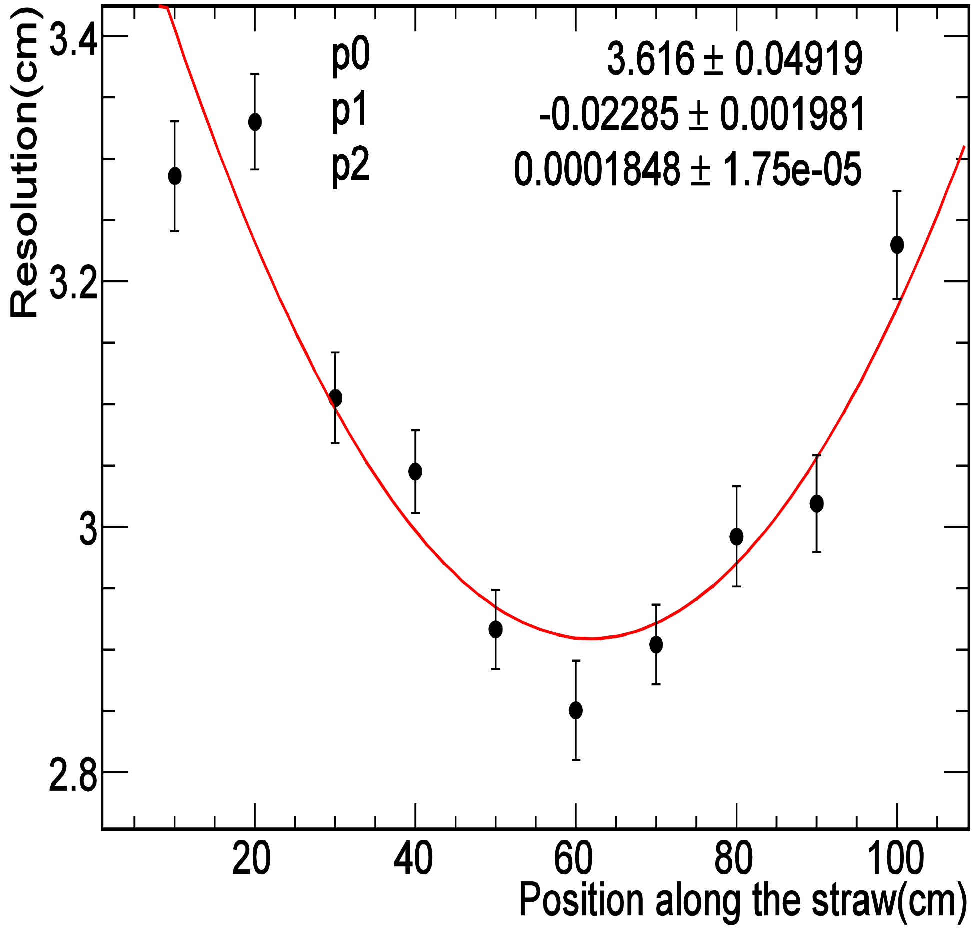
Front End Electronics



- Preamp
  - <1nsec shaping ⇔ >150MHz bandwidth
  - HV disconnect
- Digitizer:
  - CMOS ASIC digitizer ADC & TDC
  - Low power

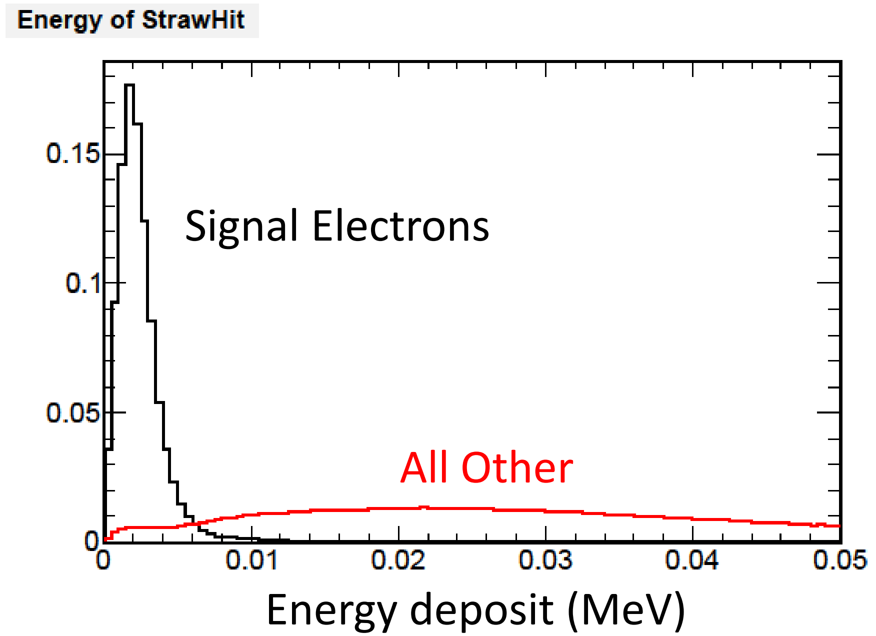
Dual TDC for Time Division

- Read out both ends, use time difference to get position along wire
- $\sigma \approx 3$cm
- Each hit can be treated as a 3D point for pattern recognition
- Stereo resolution ~0.04cm dominates fit



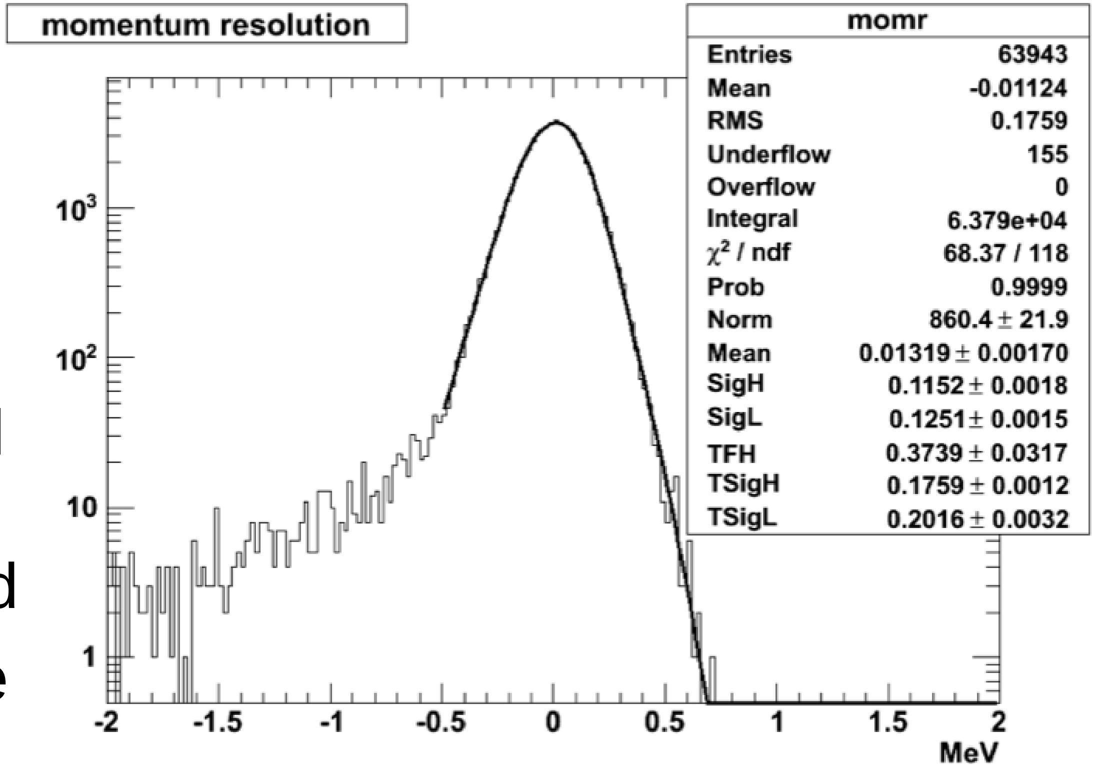
ADC for dE/dx

- Lots of protons kicked out of target
- Thin sheet of plastic stops most of these
- But … degrades resolution for electrons
- Can tolerate more protons … if we can reject based on dE/dx



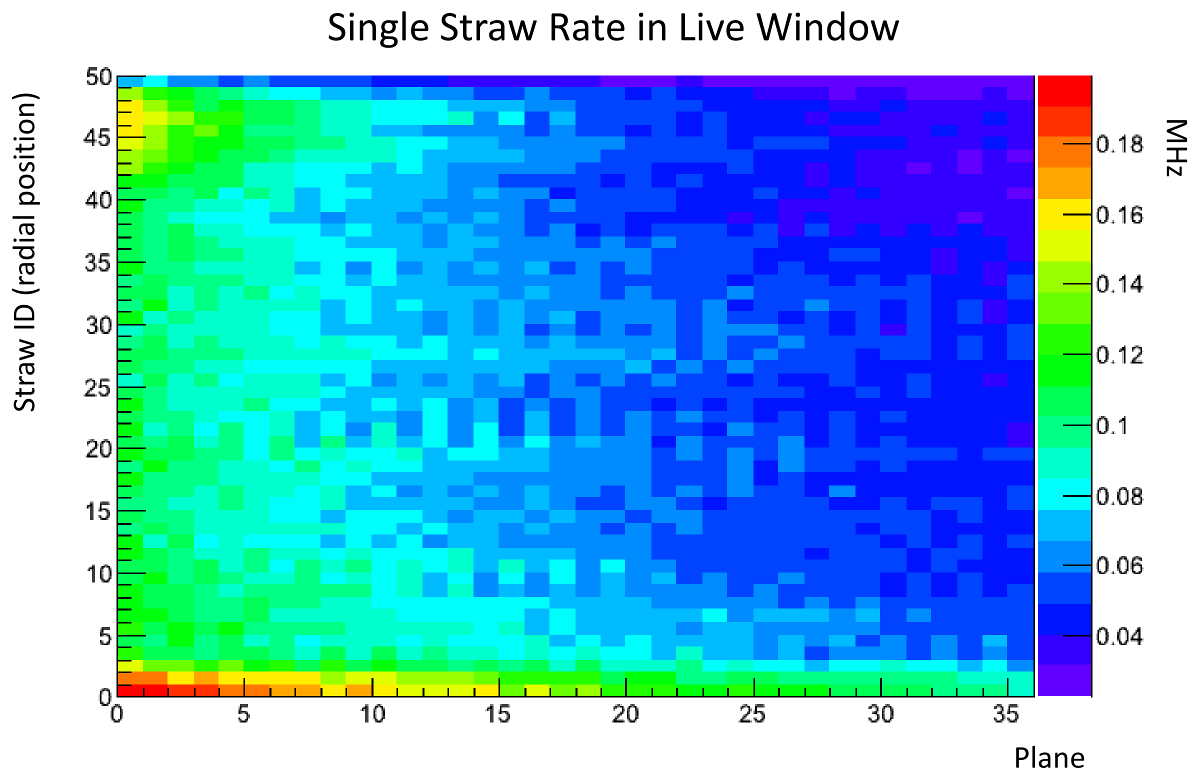
Momentum Resolution

- For 105MeV/c electrons
  - Upstream material modeled, but smearing excluded
  - Resolution relative to start of tracker



SigH	σ of core Gaussian, high side	115 KeV/c
SigL	σ of core Gaussian, low side	125 KeV/c
TFH	Fraction in the tail	37%
TSigH	σ of tail Gaussian, high side	176 KeV/c
TSigL	σ of tail Gaussian, low side	202 KeV/c

Occupancy



Hottest straw "Occupancy" ~3%

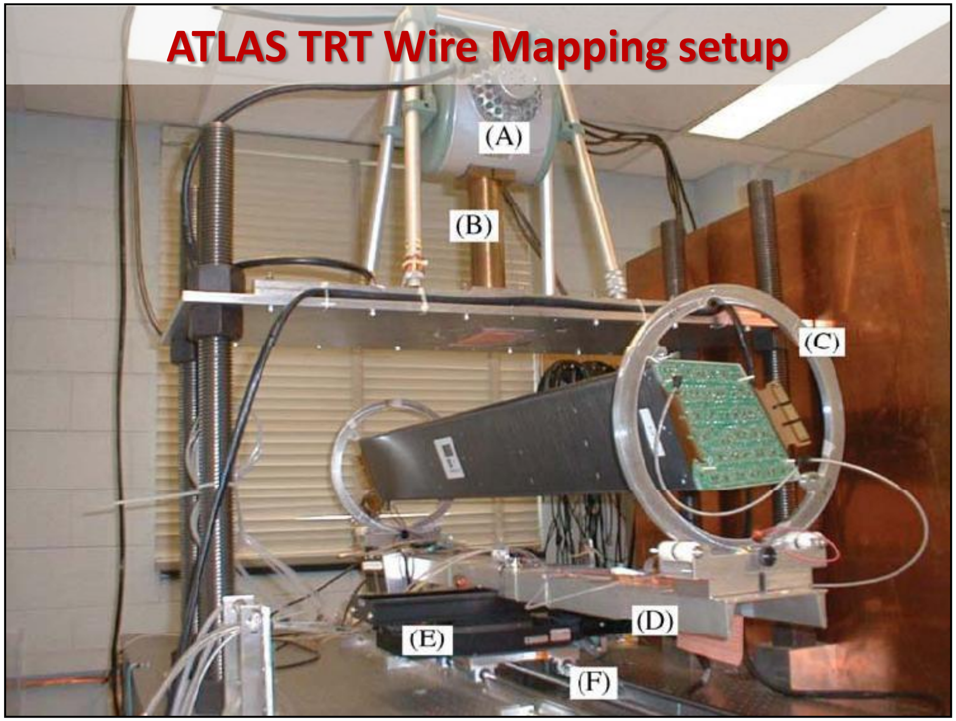
(rate $\times$ 2-track resolution)

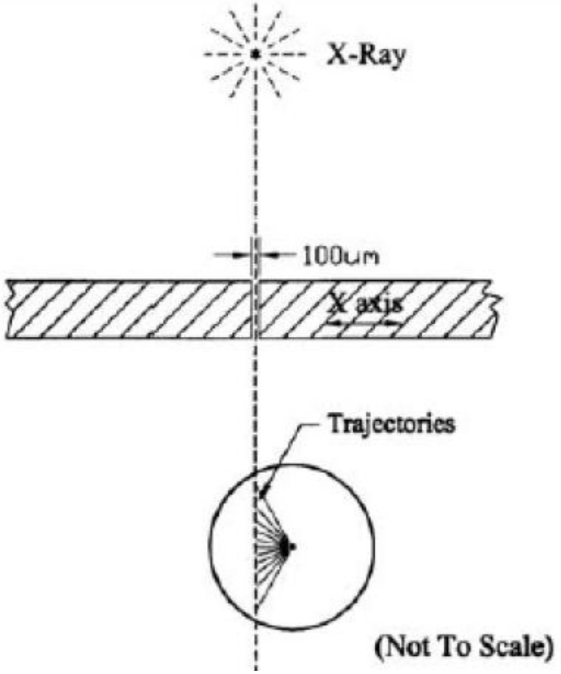
Other Requirements

- ✓ Low mass region for signal
- ✓ No mass region for DIO
- ✓ Handles rate based on ATLAS TRT
- ✓ Maintenance:
  - ✓ Stations can be swapped for repair
  - ✓ No single straw failure prevents operation
- ✓ Resolution: 118keV
- ✓ Leaks <5 ccm for full system

Alignment

- In-situ alignment unusually challenging for mu2e
  - Few cosmics underground, fewer which cross many stations
  - No simple calibration sample
- Survey wires during construction using X-ray





Straws for Other Experiments

- High rate capability
  - Common since we are all seeking a tiny signal from a huge background
- Modular
  - Each straw is a ~complete detector in itself
  - Easy to test, build, align
- Low mass for measuring low momentum particles
  - Open cell structure can be lower if ambient vacuum is not required
  - Thin wall straws developed for mu2e could help
- Pattern recognition at high occupancy
  - For long straws time division can be an assist
- Lot of experience and R&D to draw from, for mu2e and elsewhere